High-Resolution Temporal Sampling of the Nearshore Vertical Structure of Bioluminescence / Short Term Predictions of Water-Leaving Bioluminescence Radiance

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LONG-TERM GOALS

The long-term goal is to advance understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and depth-dependent variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data, this project is examining the predictability of bioluminescence events in the nearshore coastal ocean. Another aspect to this effort has been combining the bioluminescence measurements with fine-scale inherent optical properties to for the first time model bioluminescence water-leaving radiance. An added component to this project has been the preparation of a plan and strategy for the prediction of water-leaving bioluminescence radiance.

OBJECTIVES

There are three primary objectives for this project.

1 - To adapt, fabricate and deploy a moored bioluminescence system on a robotic node 5 km off the central coast of New Jersey.

2 - To quantify the physical, chemical and biological processes that define the spatial and temporal variability in bioluminescence for the nearshore coastal ocean, focusing on features associated with recurrent coastal upwelling.

3 - To take advantage of the vertical structure time series of bioluminescence and concurrent optical measurements to model bioluminescence water-leaving radiance and determine the temporal dynamics and relative importance of each input parameter.

APPROACH

As a participating scientist with the Long-Term Ecosystem Observatory (LEO-15), the goal was to collaborate with physical/biological oceanographers in integrating a new profiling capability into the existing observational network. This has been an excellent collaboration between 4 institutions (Cal Poly, UCSB, Rutgers University and Woods Hole). In addition to fabrication of the bioluminescence instrument, the general approach was to collect fine structure of bioluminescence approximately every 20 minutes and make concurrent measurements for plankton and physical/optical parameters.

Concurrent measurements were made of temperature, salinity, and sigma-t (CTD), bioluminescence potential, chlorophyll fluorescence, spectral scattering, spectral absorption, spectral attenuation, particle size/abundance (LISST), irradiance and ADCP.

WORK COMPLETED

Bioluminescence bathyphotometer (BBP) was designed, facbricated, and calibrated for this project (by UCSB) and was successfully integrated into the optical profiler (Moline and WHOI) and deployed for 15 days during the summer 2000 field effort. In 2001, there were a number of mechanical and electrical modifications that were made prior to deployment. Deployment for the 2001 field program occurred on 23rd of July in the same location as the previous year at LEO-15. Direct real-time communication and operation of the profiler and the BP was possible during 2000 and 2001 remotely through a terminal at the RUMFS. The entire deployment in 2001 lasted until August 7th for a total of 15 days. In 2001 this project also supported a joint field experiement with HIDEX to expand the horizontal scale of sampling and to compare bathyphotometers. The data for this study have been merged with the concurrently measured parameters.

RESULTS

From the time-series collected in this project, variation in the vertical structure of bioluminescence potential over the two summer experiments (2001 & 2002) was from primarily determined by vertical density structure, with longer-term changes (week-scale) coincident with episodic forcing events (i.e. upwelling/downwelling).

Summer 2000: A temperature time-series measured by the Node at LEO-15 indicated that during the deployment, the optical profiler was able to collect data through two coastal divergence events with stratification only occurring twice (http://marine.rutgers.edu/mrs/thermistors/ts/AutonomousNodeTS.html -push Entire time series and highlight station A1). The water column was well mixed when the instrument was deployed and remained so until the Julian Day (JD) 204, when an intrusion of cooler water at depth from the shelf pushed up along the coast in response to winds from the southwest, the wind direction responsible for upwelling in the region. This cold-water intrusion ended after three days and was replaced by a warm mixed homogenous water column. From JD 207 until 212, the water column remained mixed and warmed ~1.5 °C. Over the course of the deployment, surface temperatures warmed from 18 to 24 °C. On JD 202, relatively low BL signals were associated with the mixed water column. As the cold-water intrusion from the shelf intensified, the bioluminescent communities were layered and through JD 207 were strongly associated with the maximum density gradients. High bioluminescence signals of $1e^{11}$ photons/L were associated with this gradient. With the disappearance of the cold bottom water, there was a 3-4 order of magnitude decrease in BL signal. Warming of the surface layer and stratification in the final 4 days of the experiment was related to the development of another layer of high BL potential associated with the thermocline. This warm surface layer was a plume of fresh water discharge from the Hudson River to the north (Oliver et al. 2003). Despite the different mechanisms for the two periods of stratification during the 2000 experiment, the bioluminescence potential responded similarly.

Summer 2001: The period sampled in 2001 was dominated by downwelling conditions, with warm water extending throughout the water column (data not shown). A stratification of the water column was evident the first day of sampling as well as JD 217 and 218. Bioluminescence was generally an order of magnitude higher that the previous year with maximal bioluminescence potential occurring once again at the maximum gradients in the physical environment. As with the temperature, bioluminescence was relatively uniform throughout the water column during downwelling conditions. Statistical methods are presently being applied to these datasets to assess patterns and predictability. Bayesian and Markov Chain Monte Carlo modeling approaches are being pursued, as there is a temporal dependence of a particular profile on the previous measurement.

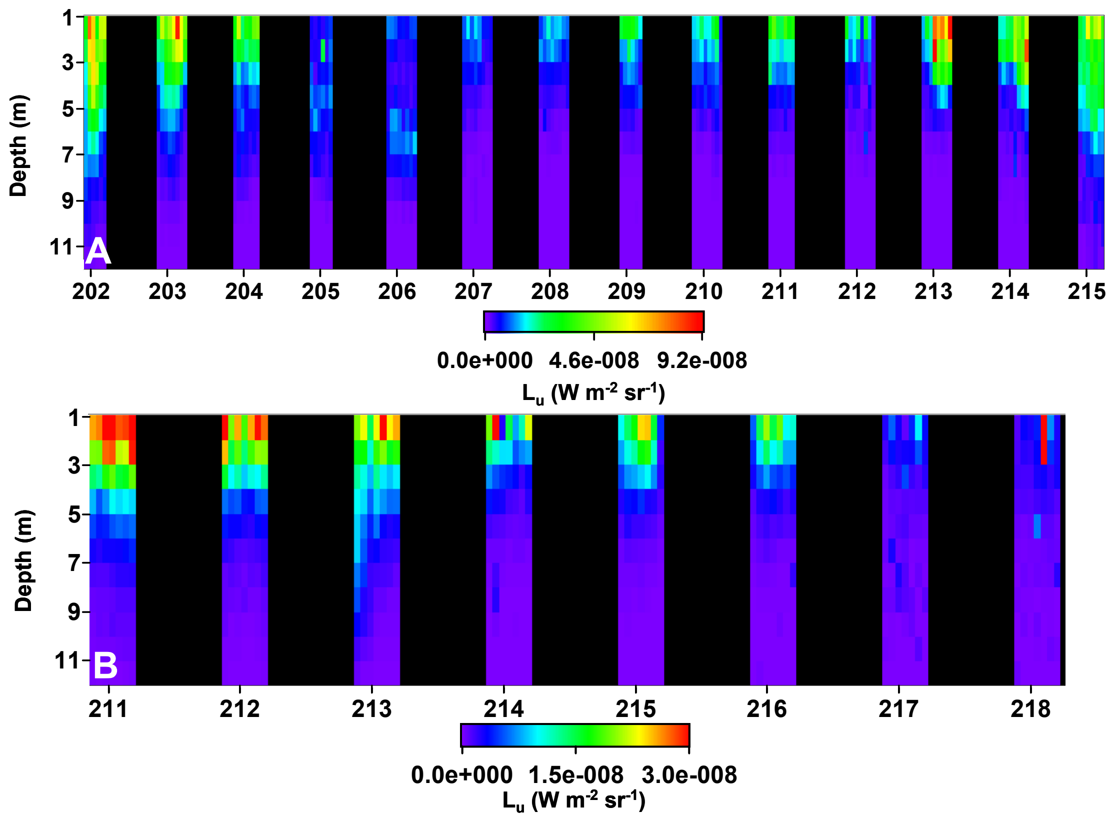

Figure 1. Estimates of surface water-leaving radiance resulting from stimulation of bioluminescent organisms in one meter depth bins during the A) 2000 and B) 2001 profiler deployments (time axis is serial calendar days).

Another objective of this project and the Navy has been to predict not only the bioluminescence potential, but also more importantly the bioluminescence water-leaving radiance (BLR). Only through the combined measurement of both optics and bioluminescence potential can this be properly addressed. The optical profiler provides the only system to date with the required optical data to undertake this effort. . The bioluminescence and optical measurements from 2000 and 2001 have been combined to estimate BLR for the first time over ecologically and militarily relevant time scales of hours to weeks (Figure 1). To quantify spectral BLR (380-700 nm), a new bioluminescence module was written (modified according to Stephany et al. 2000) and integrated into the HydroLight v. 4.2 radiative transfer model (Mobley 1994). Profiles of bioluminescence were spectrally reconstructed using known spectra from a range of dinoflagellate and copepod bioluminescence emission spectra. For each meter of every profile the bioluminescence was then propagated upward through the surface waters for 36 wavelengths using measured values of spectral absorption, attenuation, scattering, backscattering and sea state conditions as inputs into Hydrolight. For this study, 7,491 model runs were conducted to estimate the spectral BLR for the 2000 and 2001 experiments. BLR from each depth reflected the relative changes in biology and optical properties throughout the water column over both seasons (Figure 1). During 2000, BLR was high due to high bioluminescence and relatively uniform optics. As the bioluminescence stratified, the maximal leaving radiance was along the density gradients in response to the cold-water intrusion. In mixed conditions, the leaving radiance was proportional to depth as both the light and the attenuation were the similar throughout the water column. Bioluminescence increased in the last three days of the deployment due to increasing bioluminescence along the density stratification. Although there is high attenuation, it is during daylight hours and the attenuation during the night is decreasing, allowing photons generated deeper in the water column to propagate to the surface. In 2001, BLR was approximately half that of 2000 as a result of high attenuation despite higher bioluminescence. Attenuation generally increased while bioluminescence decreased, leading to a trended decrease in the BLR over time. The highest leaving radiance from depth was on JD 213 from a high bioluminescent signal. As with the spectral shift in solar radiation with depth, results quantified that there is a significant shift of over 80nm from blue to green as light propagates to the surface. Maximal bioluminescence occurs at ~474 nm, however as the depth of the bioluminescence source increases and that the proportional BLR at 474nm relative to 555nm is 40-fold less for sources at depth. Figure 2 illustrates this spectral shift with depth and the variation that occurs in response to environmental dynamics for both 2000 and 2001. The most striking spectral differences occur when the water column is optically stratified, when higher attenuating surface water and clear bottom water. During these conditions, JD 205 & 214, blue BLR occurs at nearly all depths. In downwelling conditions, maximum BLR wavelengths are from as shallow as 5 meters (JD 212) and greater than 540nm. This has significant implications for the development of sensors designed to quantify BLR, as some sources at depth will have a significantly different spectral signature (Figure 2). These findings from a single optically deep study area, suggests that the development of shore-based, ship-based, and/or airborne bioluminescence sensors (LLLII; Lynch 1981) should include the spectral range required to quantify surface stimulated bioluminescence as well as bioluminescence stimulated at depth. The actual spectral range will ultimately depend on the sensitivity of the instrument [Figure 2 shows contours of interest for a sensitivity of 1 e^{-8} ($Wm^{-2}sr^{-1}$)].

IMPACT/APPLICATION

This bioluminescence platform has advanced the ability to detect fine-scale vertical changes over time. The spectral behavior of BLR has significant implications for the development of sensors designed to quantify BLR. This exercise was also valuable in that allowed the dynamics in optics and bioluminescence to be separated and evaluated independently for their respective impacts on BLR. That will be vital when developing predictive approaches and strategies.

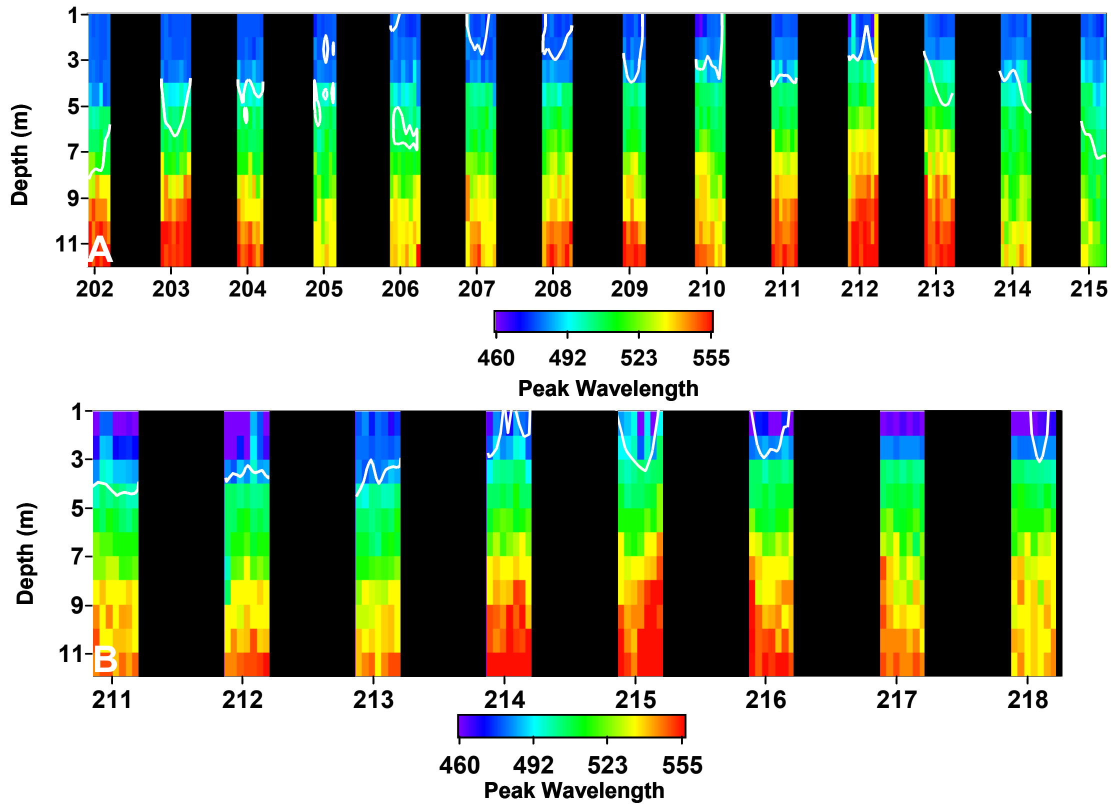

Figure 2. Time series of the depth distribution of the maximum wavelength of the BLR for A) 2000 and B) 2001. Overlaid (white lines) are the depth contours of BLR of 1 e $^{-8}$ ***(Wm*** $^{-2}$***sr*** $^{-1}$***).***

TRANSITIONS

This project added a new high-resolution nighttime bioluminescence capability. Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements will improve the ability to predict bioluminescent events in the nearshore littoral regions of the marine environment. The incorporation of optics into this program made it possible to quantify the leaving radiance over these same time scales. This is vital for Navy interests, as it is the combination of the maximum light and light propagation that will be required for tactical mission planning. In this effort, the software module to Hydrolight was written. This software is presently being developed as a transition product and adds bioluminescence to this capability.

RELATED PROJECTS

Optical profiler development was in collaboration with WHOI and Rutgers University (www.marine.rutgers.edu/mrs/). Data products from this profiler have been integrated into the ONR-HyCODE (http://www.opl.ucsb.edu/hycode.html). Collaborations with Sequoia Scientific will continue to develop a rapid accurate quantification of leaving radiance. Collaborations with James Case (UCSB) and E. Widder (HBOI) continue in order to further characterize the bioluminescent organisms in the coastal environment.

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